TABLE 4-1

SUMMARY OF ARTIFICIAL PENETRATION NON-ENDANGERMENT EVALUATION

Artificial Penetration	Cement Plug Between Injection Zone and USDW	Modeled Satisfactorily?
1	yes	N/A
2	yes	N/A
3	no	yes[1]
4	no	yes[1]
6	yes	N/A
7	yes	N/A
8	yes	N/A
10	active	N/A
11	active	N/A
16	yes	N/A
17	active	N/A
19	yes	N/A
20	no	yes[1]
21	yes	N/A
22	no	yes[1]
23	yes	N/A
24	active	N/A
25	yes	N/A
27	yes	N/A
28	yes	N/A
29	yes	N/A
30	yes	N/A
31	yes	N/A
32	yes	N/A
33	yes	N/A
34	yes	N/A
35	yes	N/A
36	yes	N/A
37	yes	N/A
38	yes	N/A
39	yes	N/A
40	no	yes[1]
41	no	yes[1]
42	yes	N/A
43	yes	N/A
44	no	yes[1]
45	yes	N/A

TABLE 4-1 (cont'd)

Artificial Penetration	Cement Plug Between Injection Zone and USDW	Modeled Satisfactorily?
46	yes	N/A
47	no	yes[1]
48	yes	N/A
49	yes	N/A
50	yes	N/A
51	yes	N/A
52	yes	N/A
53	yes	N/A
54	yes	N/A
55	yes	N/A
56	yes	N/A
57	yes	N/A
58	active	N/A
59	yes	N/A
60	yes	N/A
61	yes	N/A
62	yes	N/A
63	does not penetrate injection intervals	N/A
64	yes	N/A
65	does not penetrate injection intervals	N/A
66	does not penetrate injection intervals	N/A
67	yes	N/A
68	yes	N/A
69	does not penetrate injection intervals	N/A
70	no	yes[1]
72	no	yes[1]
73	yes	N/A
74	no	yes[1]
75	does not penetrate injection intervals	N/A
76	yes	N/A
77	yes	N/A
78	yes	N/A

[1] See Tables 4-2 and 4-3

TABLE 4-2

SABINE RIVER WORKS
ARTIFICIAL PENETRATION DATA FOR MODELING
5400' M SAND

This is most [illegible] w/ [illegible] [illegible] 6-17-91

AP (ft)	TD (ft)	DEPTH TO INJECTION INTERVAL (psi)[1]	ORIGINAL FORMATION PRESSURE (psi)[2]	STATIC COLUMN W/9 LB MUD (psi)[3]	ALLOWABLE BUILDUP W/9 LB MUD (psi)[4]	ACTUAL MUD WEIGHT (lb/gal)[5]	STATIC COLUMN W/ ACTUAL (psi)[6]	ALLOWABLE BUILDUP W/ ACTUAL (psi)[7]	MODELED BUILDUP (psi)[8]
3	8108	5417	2448	2535	87	9 BRINE	2535	87	28
4	8175	5383	2433	2519	86	10	2799	366	28
20	8080	5520	2495	2584	88	10	2871	375	28
22	8088	5501	2486	2575	88	10	2861	374	27
40	8075	5371	2428	2514	86	MUD-LADEN >9	2514	86	36
41	8101	5381	2432	2518	86	MUD-LADEN >9	2514	86	38
44	8088	5380	2432	2518	86	MUD-LADEN >9	2518	86	37
47	UNKNOWN	5410	2445	2532	87	>9	2532	87	48
70	8980	5421	2450	2537	87	10	2819	369	29
72	8514	5268	23841	2466	84	11.5	3150	769	22
74	9700	5112	2311	2393	82	16.5	5386	3076	25

1 Depth to top of injection interval.
2 Original formation pressure in injection interval.
3 Static pressure of 9.0 lb/gal mud column, no credit for gel strength, etc.
4 Static pressure of 9.0 lb/gal mud column minus original formation pressure = allowable pressure increase prior to initiating fluid movement in borehole.
5 Weight of fluid left in wellbore at abandonment.
6 Static pressure of mud column using actual weight of fluid left in wellbore, no credit for gel strength, etc.
7 Static pressure of actual column of mud minus original formation pressure = allowable pressure increase prior to initiating fluid movement in borehole.
8 Modeled pressure buildup based on maximum permitted injection rates until the year 2000.

TABLE 4-3

SABINE RIVER WORKS
ARTIFICIAL PENETRATION DATA FOR MODELING
4600' J SAND

AP (ft)	TD (ft)	DEPTH TO [1] INJECTION INTERVAL (psi)	ORIGINAL [2] FORMATION PRESSURE (psi)	STATIC [3] COLUMN W/9 LB MUD (psi)	ALLOWABLE [4] BUILDUP W/9 LB MUD (psi)	ACTUAL [5] MUD WEIGHT (lb/gal)	STATIC [6] COLUMN W/ ACTUAL (psi)	ALLOWABLE [7] BUILDUP W/ ACTUAL (psi)	MODELED [8] BUILDUP (psi)
3	8108	4637	2096	2170	74	9 BRINE	2170	74	10
4	8175	4598	2078	2152	74	10	2391	313	10
20	8080	4717	2132	2208	76	10	2452	321	10
22	8088	4706	2127	2202	75	10	2447	320	10
40	8075	4605	2081	2155	74	MUD-LADEN >9	2155	72	13
41	8101	4591	2075	2149	74	MUD-LADEN >9	2149	74	13
44	8088	4585	2072	2146	73	MUD-LADEN >9	2146	74	12
47	UNKNOWN	4570	2066	2139	73	9	2139	73	15
70	8980	4531	2048	2121	73	10	2356	308	14
72	8514	4580	2070	2144	73	11.5	2145	96	13
74	9700	4382	1981	2051	70	16.5	384	1893	14

1 Depth to top of injection interval.
2 Original formation pressure in injection interval.
3 Static pressure of 9.0 lb/gal mud column, no credit for gel strength, etc.
4 Static pressure of 9.0 lb/gal mud column minus original formation pressure = allowable pressure increase prior to initiating fluid movement in borehole.
5 Weight of fluid left in wellbore at abandonment.
6 Static pressure of mud column using actual weight of fluid left in wellbore, no credit for gel strength, etc.
7 Static pressure of actual column of mud minus original formation pressure = allowable pressure increase prior to initiating fluid movement in borehole.
8 Modeled pressure buildup based on maximum permitted injection rates until the year 2000.

APPENDIX 4-1

Artificial Penetration Protocol

ARTIFICIAL PENETRATION PROTOCOL

As used in current regulations, the AOR pertains to the area within which the owner or operator of Class I injection wells must identify all artificial penetrations that penetrate the permitted confining and injection zones. The following is an outline of the steps taken to identify and evaluate artificial penetrations in an AOR.

WELL IDENTIFICATION

Data Sources

A specific and consistent methodology was used to identify all artificial penetrations within the AOR surrounding each Du Pont injection well. Several data sources were utilized to locate pertinent information regarding each artificial penetration. Revised or updated base maps, such as Cambe Geological Services, Zingery Map Co., Tobin Surveys, United States Geological Survey, state regulatory maps, and state highway county maps were utilized to initially identify and establish a general background on the wells in each AOR. State agency files along with state libraries were researched by AIC for well descriptive documentation (see Appendix 4-5, State Forms). Du Pont internal documents such as old abandoned well studies, well replugging documents, maps, reservoir pressure studies, and well schematics were gathered from the Du Pont Information Center at the Gulf Coast Regional Consulting Office (IC-GCRC) in Beaumont, Texas. Commercial log service companies with regional libraries such as Cambe Geological Services, Incorporated and Petroleum Information were researched for well logs and scout tickets. Additional records data were obtained through oil company sources. Wells lacking data after utilizing the primary resources were researched by contacting original/current operators, lease owners and consulting geologists familiar with that area. Where discrepancies existed among data sources, state form data were considered to be the most accurate.

A number of oil and gas wells were permitted but have never been drilled. These expired permit surface locations sometimes have been erroneously spotted as oil and gas wells on certain base maps by cartographer error. The proposed wells, of course, have no construction, plugging or operation records and were verified as being nonexistent by the state agency responsible for records in that area. Wells that were identified as having been drilled but missing the necessary records to document adequacy of plugging and/or construction were labeled potential problem wells and modeled for possible vertical fluid migration.

Corrective Action Plan

Potential problem wells that fail the pressure model are labeled "problem wells" as they constitute a potential threat to USDWs. If vertical fluid migration is calculated for any of the potential problem wells, then one of the following steps must be taken:

1. locate and re-enter the problem well to plug properly,

2. lower the injection rate to reduce pressure (head) driving force,

3. recomplete the injection well at a greater depth so that the problem well can tolerate a higher pressure without fluid migration,

4. recomplete the injection well in an interval deeper than the problem well penetrates,

5. increase the density of the injected waste to prevent vertical fluid migration,

6. drill a monitor well next to the problem well to monitor possible vertical fluid migration.

Other Disposal Operations

State or Federal agencies responsible for permitting UIC operations will rarely permit Class I injection wells in an area where injection (Class I and Class II), in the same zone, is already taking place. If injection wells (saltwater disposal, enhanced recovery, or other) were found in or near the AOR, operation and completion records were obtained for those wells. Injection intervals and volumes injected were researched and subsequently modeled to show if significant pressure increases were resulting from the additional injection source(s).

Data Organization

After each data source was reviewed and pertinent data had been extracted, each artificial penetration was given an identification number (map identification number = artificial penetration). A base location map was built from all of the base maps showing each artificial penetration at its proper location (see Appendix 4-4, Maps).

REFERENCES

Johnston, O. C., and Knape, B. K., 1986, Pressure Effects of the Static Mud Column in Abandoned Wells: Texas Water Commission LP86-06, p. 99, [0110880].

Texas Railroad Commission, 1986, Statewide rules for oil, gas and geothermal operations: Austin, Texas, p. 172, [0111525].

APPENDIX 4-2

Artificial Penetration Model

Individual well records were checked to address the problems of lost circulation zones or a decrease in mud column height from removal of casing for salvage (Johnston and Knape, 1986, p. 7). Identification of either of these problems in an abandoned well would mean modeling that abandoned well with less than a full column of mud or by another method.

Static mud column pressure should vary little from actual pressure because errors in density gradient should offset each other. Gel structure would be expected to increase with depth because of settling of particles through time. The assumption of uniform mud consistency provides the only means of calculating gel strength pressure, because gel strength variations in a mud column are unknown.

2. Abandoned borehole diameter = bit diameter + 2 (in.) in the calculations, where bit refers to the bit size used to drill the hole at the depth of the injection formation.

Justification: Gel strength pressure is inversely proportional to well bore diameter. To compensate for larger surface casing, the effective diameter of the abandoned well bore is the bit diameter used to drill the injection formation plus 2 in. The additional two in. also allows for borehole irregularities (washouts) and will provide a conservative result. The 2-in. allowance prevents having to model the larger diameter surface casing separate from the bit size used to drill the injection zone.

3. Injection pressures will not exceed fracture pressure of the injection formation (a requirement for permitting).

4. Known abandoned wells for which data are unavailable or incomplete are assigned a mud density of 9 lb/gal and the largest bit diameter noted for all wells within a 2.5 mile radius of the injection well(s).

Justification: Mud density of 9 lb/gal is the allowed (and conservative) minimum mud weight (Price, 1972; Collins, 1986; Davis, 1986; Johnson and Knape, 1986; and Alford, 1987). If a lesser mud density were found in other abandoned wells within a 2.5 mile radius of the injection well(s), then the lesser mud density would be used. (A discussion of mud density has been previously made.) Because gel strength is inversely proportional to bit size, the largest bit size provides the most conservative value for gel strength.

5. Abandoned wells were either: 1) dry holes, or 2) production wells with production casing removed and which have records indicating that the borehole was filled with mud at abandonment.

Justification: In either case, mud fills the borehole. In an abandoned dry hole the mud is drilling mud; in an abandoned producer the fluid is usually labeled "heavy mud" or "mud-laden". Mud density may range depending on the regulations in force at time of abandonment.

6. Pressure exerted by the static mud column was calculated at the top of the injection formation.

Justification: Pressure due to injection is assumed to spread throughout the thickness of the zone, and thus be evenly distributed. Calculating the static mud column pressure at the top of the injection formation is conservative because the height of the mud column is a minimum.

7. In calculating mud gel strength, all abandoned wells were drilled with water-based muds (fresh water, salt water, oil-in-water emulsions, and surfactant muds).

Justification: Oil-based drilling muds, and gas and air drilling fluids lack gel strength associated with water-based drilling fluids. Abandoned boreholes drilling with non-water based drilling fluids were not evaluated for gel strength.

8. Gel strength, if used, is assumed to be 20 lb/(100 ft^2).

Justification: Although some work remains to be done on mud gel strength, what is known has been covered in the literature (for example, Barker, 1981; Collins, 1986; Johnston and Knape, 1986). Below is a summary, because currently no credit is given by regulatory agencies for mud gel strength.

Gel strength is the property of mud which acts to suspend drill cuttings in the static mud column when circulation stops. Gel strength forms as a function of: 1) the amount and type of clays in suspension, 2) time, 3) temperature, 4) pressure, 5) pH,a and 6) chemical agents in the mud.

The pressure required to displace the gel can be large, and gel strength may be the main factor in preventing fluid migration within an abandoned well bore (Collins, 1986; Johnston and Knape, 1986).

Barker (1981) determined, under the wide variety of factors contributing to mud gel strength, that 20 lbs/100 ft^2 was a valid conservative (minimum) estimate of mud gel strength. Gray and Darley (1981) determined that approximately 20 lb/100 ft^2 was the lowest possible gel strength that could occur. Thus, 20 lb/100 ft^2 is a reasonable and conservative value for mud gel strength and is used in these calculations where needed.

9. None of the wells which were modeled were properly plugged.

Justification: Pressure calculations are made equitably on static mud columns in abandoned boreholes when all are considered unplugged.

Procedure-Using the Model

1. Locations of all artificial penetrations were digitized from a base map on a Tektronix digitizing tablet linked to a Tektronix T4054 graphics computer.

2. The distance from an artifical penetration to the injection well(s) was then used in the modeling program (see Section 2, Flow and Containment Modeling) to calculate the increase in pressure in an injection interval at the artificial penetration location. The model sums the pressures due to injection from all (if more than one) of the waste wells in an injection interval. Where there is more than one injection interval, pressure due to injection was calculated for each interval modeled. Use of the abandoned well model implies the same assumptions, benefits, and limitations of modeling the waste wells themselves, unless otherwise stated.

3. Information on mud density, bit size, casing size (where applicable) and depth to the uppermost injection sand for an artifical penetration was obtained from the following sources in order of priority:

a. State forms
b. Geophysical log(s), scout cards, other sources of data

Original formation pressure in each injection sand was obtained from one or more of the following (see Flow and Containment Modeling):

a. Bottomhole pressure surveys
b. Pressure modeling of the injection zones
c. Wellhead shutin pressures and density of fluid in the well bore

Original formation pressure at the injection well(s) is corrected for depth in the artificial penetrations by using the gradient determined by original formation pressure at the injection well(s). Original formation pressure in the artificial penetration was calculated at the top of the injection sand.

4. Depth to the uppermost injection sand was determined from geophysical logs. Depths to other injection sand were calculated by adding the distance to the uppermost injection sand to the incremental thicknesses of the injection sands and confining layers based on the pressure modeling parameters.

5. The abandoned well model was run for each injection sand as required using the above noted data.

6. Model outputs include (for each injection sand):

a. Pressure increase above original formation pressure through time, from the beginning of injection at the Du Pont plant through the projection period.

b. Indication of one of the following about the status of the abandoned well with 9 lb/gal mud and no gel strength credit (Case 1):

1) migration of fluids in the abandoned well bore will not occur through the next projected time period of continued waste injection, or

2) migration of fluids in the abandoned well bore does not occur presently, but may occur within the next projected time period, or

3) migration of fluids in the abandoned well bore may be occurring now.

c. Indication of one of the following about the status of the abandoned well with actual mud density and minimum credit for gel strength (Case 2):

1) migration of fluids in the abandoned well bore will not occur through the next projected time period of continued waste injection, or

2) migration of fluids in the abandoned well bore does not occur presently, but may occur within the next projected time period, or

3) migration of fluids in the abandoned well bore may be occurring now.

Results of Model

Further investigation or remedial action is indicated if output from the model indicates that there is fluid migration occurring in a borehole.

SAMPLE CALCULATIONS OF STATIC MUD COLUMN PRESSURE

Hypothetical case:

a. original formation pressure 1750 psi at 4000 ft BLS (injection zone)

b. actual mud weight in abandoned well = 10.4 lb/gal

c. minimum gel strength of 20 lb/100 ft^2

d. borehole radius 9 7/8 in. (add 2 in. for rugosity and irregularities = 11 7/8 in.)

Case 1:

Static mud column pressure assuming 9 lb/gal mud (conservative value) in borehole and not allowing for gel strength:

(0.052) x (4000 ft) x (9 lb/gal) = 1872 psi

1872 psi - 1750 psi (original pres.) = 122 psi buildup allowed

Case 2:

Static mud column pressure using actual mud weight and not allowing for gel strength:

(0.052) x (4000 ft) x (10.4 lb/gal) = 2163 psi

2163 psi - 1750 psi (original pres.) = 413 psi buildup allowed

Case 3:

Static mud column pressure using actual mud weight and allowing for minimum gel strength (20 lb/100 ft^2):

[(0.052) x (4000 ft) x (10.4 lb/gal)] + [(0.00333) x
(20) x (4000 ft) / (11.875)] = 2185 psi

2185 psi - 1750 psi (original pres.) = 435 psi buildup allowed

The results of these sample calculations are summarized:

BUILDUP ALLOWED AT ABANDONED WELL

Case 1 -	9 lb/gal mud, no gel strength	122 psi
Case 2 -	actual mud wt.; no gel strength	413 psi
Case 3 -	actual mud wt.; min. gel strength	435 psi

Obviously, calculations with actual mud weight, with or without gel strength credit, would allow a much higher buildup of pressure than allowing only 9 lb/gal mud.

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Appendix 4-3

SCOUT TICKETS

(See Binder)